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The progression of myopia from its onset at age 8–12 to adulthood and the influence of heredity and external factors on myopic progression. A 23-year follow-up study

Olavi Pärssinen,[1,2] Markku Kauppinen[2] and Anne Viljanen[2]

[1]Department of Ophthalmology, Central Hospital of Central Finland, Jyväskylä, Finland
[2]Department of Health Sciences and Gerontology Research Center, University of Jyväskylä, Jyväskylä, Finland

ABSTRACT.
Purpose: **To examine myopic progression and factors connected with myopic progression.**
Methods: **Myopic schoolchildren, with no previous spectacles, 119 boys and 121 girls, were recruited during 1983–1984 to a randomized 3-year clinical trial of bifocal treatment of myopia with a subsequent 20-year follow-up. Participants' mean age at Baseline was 10.9, ranging from 8.7 to 12.8 years. An ophthalmological examination was carried out annually for 3 years and twice thereafter at ca. 10-year intervals. Additional refraction values were received from prescriptions issued by different ophthalmologists and opticians. Altogether, 1915 refraction values were available. Reading distance and accommodation were measured at each control visit. Data on parents' myopia, daily time spent on reading and close work, outdoor activities and watching television were gathered with a structured questionnaire.**
Results: **Using bifocals (+1.75 add) or reading without glasses or accommodation stimulus during the 3-year period in childhood did not correlate with adulthood refraction. Short reading distance in childhood predicted higher adulthood myopia among females. The factors predicting faster myopic progression were parents' myopia and less time spent on sports and outdoor activities at childhood. Time spent on reading and close work in childhood was related to myopic progression during the first 3 years but did not predict adulthood myopia. Myopia throughout follow-up was higher among those who watched television <3 hr daily than those who spent more time watching television. Mean myopic progression 8 years after age 20–24 was −0.45 D ± 0.71 (SD), and in 45% of cases, progression was ≥0.5 D.**
Conclusions: **In nearly half of the cases, myopia beginning at school continued to progress into adulthood. Higher adulthood myopia was mainly related to parents' myopia and less time spent on sports and outdoor activities in childhood.**

Key words: follow-up – aetiology – myopia – outdoors – prevalence – progression reading – TV

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Introduction

Myopia can begin at any age but begins in most cases at school age. The prevalence of myopia and its rate of progression vary widely according to several factors (e.g. ethnicity, population, age, gender, occupation and education). Hereditary factors have been reported in relation to refraction and myopia (Teikari et al. 1991; Pärssinen et al. 2010). Recent genomewide studies have shown several gene loci which are associated with ocular refraction and myopia (Verhoeven et al. 2012, 2013). However, the worldwide trend towards an increase in the prevalence of myopia is hard to explain outside of environmental factors (Vitale et al. 2009; Pärssinen 2012). Several studies have connected the prevalence of myopia with higher education and occupational status (Pärssinen 1987; Teasdale et al. 1988; Kinge et al.1998).

There is some evidence that myopic progression could be connected with more time spent on reading and close work and less time spent on sports and outdoor activities among children. Saw et al. (2002) found that children aged 7–9 years with greater current reading exposure were more likely to be myopic. A follow-up study by Yi & Li (2011) in 7- to 11-year-old school children showed a connection between slower myopic progression and more outdoor activities, more time spent wearing glasses, more time spent in natural light and less time using a computer. However, the causative role of these variables on myopic progression has not gone unquestioned in all studies (Jones-Jordan et al. 2011). Studies on the connections between time spent watching TV and myopia have not shown significant correlations (Czepita et al. 2010; Wu et al. 2010).

To date, it remains unclear precisely what factors influence the increase in myopia prevalence, and in what way, and which of the two factors, reading and close work or time spent on sports and outdoor activities, is more connected with the progression of myopia. Does the time spent on sports and outdoor activities *per se* prevent myopia or is the connection between these factors explained simply by the absence from reading and near-work activities?

The results of the first 3-year follow-up study of the subjects of the present study showed that the factors with the most significant relationships to myopic progression were female gender, young age of onset and high degree of myopia at Baseline (Pärssinen & Lyyra 1993). Faster myopic progression and higher myopia at the end of 3-year follow-up were related to more time spent on reading and close work and to short reading distance but not, however, to accommodation stimulus (Pärssinen & Lyyra 1993). When the same subjects were studied 10 year later, the rate of myopic progression was related to the level of education among those whose myopia begun at the fifth grade of school, but not among those whose myopia begun 2 years earlier at the third grade (Pärssinen 2000).

The aim of this study was to examine myopic progression in the same subjects from its onset at school age onwards into adulthood and to study to what extent the rate of myopic progression is explained by individuals' patterns of spending time and parental myopia.

Materials and Methods

Study subjects

This study consisted of 240 myopic schoolchildren with a mean age of 10.9, range 8.7–12.8 years, who were recruited during the years 1983–1984 to a randomized clinical trial of myopia treatment (Hemminki & Pärssinen 1987). The children from grades III or V of basic school who had poor distant vision at screening were sent for an ophthalmological examination. All participants were born Finns resident in the Central Hospital of Central Finland Health Care District. The main inclusion criteria were spherical refraction > -3D, astigmatism ≥ -2 D, spherical equivalent (SE) ≥ -3 D, no other eye diseases and no previous glasses for myopia. The more detailed inclusion and exclusion criteria have been described earlier (Hemminki & Pärssinen 1987). One hundred and nineteen boys and 121 girls were randomly allocated to three different treatment groups according to the recommended use of spectacles: continuous use, only for distant use and bifocals with a 1.75 D add. An annual examination (Follow-ups 1, 2 and 3) was conducted for 3 years. Follow-up 3 at the mean age of 13.9 years was conducted for 238 of them (Pärssinen & Lyyra 1993). The next clinical follow-up (age 24 follow-up) was subsequently conducted about 13 years after the Baseline for 179 (74.6%) subjects (Pärssinen 2000). The mean age of the subjects at that examination was 23.7 years, ranging from 20.9 to 26.9 years. The last clinical examination (age 35 follow-up) was carried out for 134 (55.3%) subjects. Their mean age was 34.7 years (ranging from 31.9 to 37.4 years.). Mean years of education was 15.6 ± 3.3, and in 93% of cases, it was >12 years. All the examinations were performed by the same ophthalmologist (author OP).

The subjects participating in the two last clinical follow-up examinations did not differ from the non-participating subjects in initial refraction (p = 0.261, *t*-test) or Follow-up 3 refraction (p = 0.812, *t*-test), age at entry to the study (p = 0.662, *t*-test), sex (p = 0.088, chi-square test), parents' myopia (p = 0.590, chi-square test), time spent on Reading and close work (p = 0.915, *t*-test), or Outdoor activities (p = 0.835, *t*-test) or watching TV (p = 0.586, *t*-test).

Fourteen (5.8%) of those non-participating in the last examination were living in foreign countries or their addresses could not be found, and in seven cases (2.9%), the reason for non-participation was busy work schedules. Of the remaining non-participants, only 16 (6.6%) lived within 100 km of the examination centre.

Additional refraction values were received from prescriptions and records of different ophthalmologists and opticians. When both the results of the clinical examinations and the prescriptions issued between the clinical examinations were taken into account, 1915 refraction values for both eyes (median number of examinations for the subjects was eight, range 2–15) were obtained across the whole follow-up. To obtain the maximum number of refraction values for the analyses at adult ages, the refraction values from the clinical measurements and prescriptions were pooled and the adult cases further divided into two age groups, 20–24.99 years (follow-up 4, with mean age of 22.9 years) and 25 years and older (Follow-up 5, with mean age of 31.9 years, range 25–39 years). The first of the highest myopic SE values available at those age groups for each subject was selected. Subsequently, in the analysis of myopic changes, the measurement points are shown according to the relevant age range: 8–12 (Baseline), 10–14 (Follow-up 1), 11–15 (Follow-up 2), 12–16 (Follow-up 3), 20–24 (Follow-up 4) and 25–39 (Follow-up 5). Refraction values from all the measurement points were available from 146 subjects. At end point (Follow-up 5), that number included 15 refraction values from prescriptions of different ophthalmologists and opticians.

Two subjects died during the follow-up, and their data were included in the analysis up to the last follow-up point. In 17 cases, refractive surgery was performed. In those cases, the last preoperative refraction was regarded as their final refraction. Keratoconus had been diagnosed in two cases, which were excluded. At the last examination in one subject, the childhood SEs, -3.00 D and -2.75 D, had changed to hyperopic refraction, SE $+1.13$ D and $+0.25$ D, in the right and left eye, respectively. This individual suffered from thyroid and parathyroid insufficiency and sarcoidosis, and was on cortisone, thyroxin and calcium medications, and thus was also excluded.

The study was approved by the ethics committee of the Central Hospital of Central Finland. Our research adhered to the tenets of the Declaration of Helsinki.

Questionnaires

The child and accompanying parent(s) were given a questionnaire at Baseline and at the three subsequent annual control visits asking about background characteristics. The questionnaire at Baseline and at Follow-up 3 asked for the average time, to within half an hour, spent on Reading and other types of close work carried out outside school (Reading) separately for school-days and weekends. The average time spent on sports and Outdoor activities, including time spent on the way to school (Outdoor) and watching television (TV), was similarly elicited. The mean daily time in hours used for these activities was calculated from the answers at the beginning and at the 3-year control visit. At the age 24 and 35 control visits, open questions were asked about the hours spent on Reading, Outdoor activities and TV. At the age 35 control visit, the time spent on Reading and on a computer was combined. Length of education in years and level of education were asked at the age 24 and 35 control visits. School grade point average (GPA from 4 to 10) was asked at each visit. The questionnaire was also used to determine whether one or both parents were myopic (but not the actual refraction values). Parents were regarded as myopic if one or both of them were myopic.

Clinical examination

Subjective refraction, by the fogging method, was carried out at Baseline and at the three subsequent annual visits about 45 min after applying two drops of 1% cyclopentolate hydrochloride (Oftan Syklo®, Star, Tampere, Finland) to each eye. At the 24- and 35-year follow-up visits, only 1 drop of 1% cyclopentolate hydrochloride (Oftan Syklo®, Santen, Tampere, Finland) was applied to the right eye and one drop of 0.5% tropicamide (Oftan Tropicamid, Santen®) to the left eye (for not inducing long-standing binocular cycloplegy). The final spherical refraction was controlled by the red–green test. Spherical equivalent (SE) was calculated and regarded as the refraction value of the eye. Reading distance was measured at each clinical examination with a Clement Clark's accommodometer. The mean of the four childhood measures was regarded as the childhood reading distance. The average accommodation stimulus in childhood was calculated from the refraction values at different reading distances (Pärssinen et al. 1989). Myopia and myopic progression and way of wearing spectacles were accounted for in these calculations. The customary ophthalmological examination included among other things, biomicroscopy, ophthalmoscopy and biometric measurements and measurement of intraocular pressure.

Statistical methods

Student's *t*-test and one-way ANOVA were used to test differences between independent groups (e.g. gender, way of using spectacles) in the case of continuous variables. Differences in SE between eyes were analysed using paired-samples *t*-test. The associations between continuous variables (e.g. age, myopic progression, time spent in different activities) were analysed by Pearson product moment correlation coefficients. Generalized linear model (GLM) for repeated measures was used to analyse the difference in changes in myopic progression over the follow-up time. These models allow many between-effects factors and covariates to be included in the model (e.g. gender, parent's myopic status and different activity levels in our analyses were used).

General statistical analyses were performed using SPSS version 19.0 (IBM Corporation, New York, NY, USA) software and Stata version 12.0 (Stata Corp., College Stations, TX, USA). The level of statistical significance was set at $p < 0.05$ (two-sided).

Results

There were no statistically significant differences in SE between the right, −1.43 D ± 0.59 (SD), and the left eye, −1.47 D ± 0.60, at the beginning of the study (p = 0.153, paired-samples *t*-test) or at the end of the follow-up (25–39 years), SE −5.02 D ± 2.23 and −5.06 D ± 2.14 (p = 0.599, paired-samples *t*-test). Next, only the SE values of the right eye were used. Refractive surgery had been performed for 17 subjects. Their refraction in childhood (Follow-up 3) was −3.20 D ± 1.19 as compared to 3.06 D ± 1.19 (p = 0.638, paired-samples *t*-test) in non-operated persons. Similarly, preoperative SE (−5.12 D ± 2.01) did not significantly differ from that of non-operated persons (−5.19 D ± 1.53) (p = 0.889, paired-samples *t*-test).

Wide variation was found in the individual progression of SE. In most cases, the increase in myopia was fastest at the beginning and gradually slowed down. In some cases, there were slight temporary or permanent improvements. Figure 1 shows the individual refraction curves (SE) for all the study subjects, based on all the refraction values available, separately for boys and girls. For better visualization of the individual refraction curves, the results are further divided into two age groups according to the median age of myopia onset.

The younger the child was at the beginning of the follow-up, the greater the rate of myopic progression ($r = -0.430$, $p < 0.001$, Pearson product moment correlation). The rate of myopic progression at the whole follow-up was not related to the amount of myopia at the beginning of the study ($r = -0.082$, p = 0.272).

Table 1 shows the changes in refraction for males and females together between the Follow-ups 3 (mean age 14 ± 1.1 years), 4 (mean age 23 ± 1.2 years) and 5 (mean age 31 ± 1.7 years). From Follow-ups 3 to 5, the mean change in refraction was −2.12 ± 1.30 D. The increase in myopia was ≥5 D in only 3.5% of cases. Between Follow-ups 4 and 5, the mean increase in myopia was −0.45 D ± 0.71 and the annual change −0.05 D ± 0.09. In about half of the cases, the change of refraction remained within the limits of < ±0.50 D between Follow-ups 4 and 5. In 17.9% of cases, the increase in myopia was ≥1.00 D and was ≥2.5 D in only one case. In 4.0% of cases, myopia decreased by 0.5–1.5 D.

Gender

The increase in myopia was faster among females than among males ($p < 0.001$, repeated-measures ANOVA with repeated contrasts) up to Follow-up 4 (20- to 24-year-olds). Later, the progression of SE stabilized (p = 0.337). A gender difference was observed over the follow-up time (p = 0.035). The faster progression of myopia of girls was not explained by

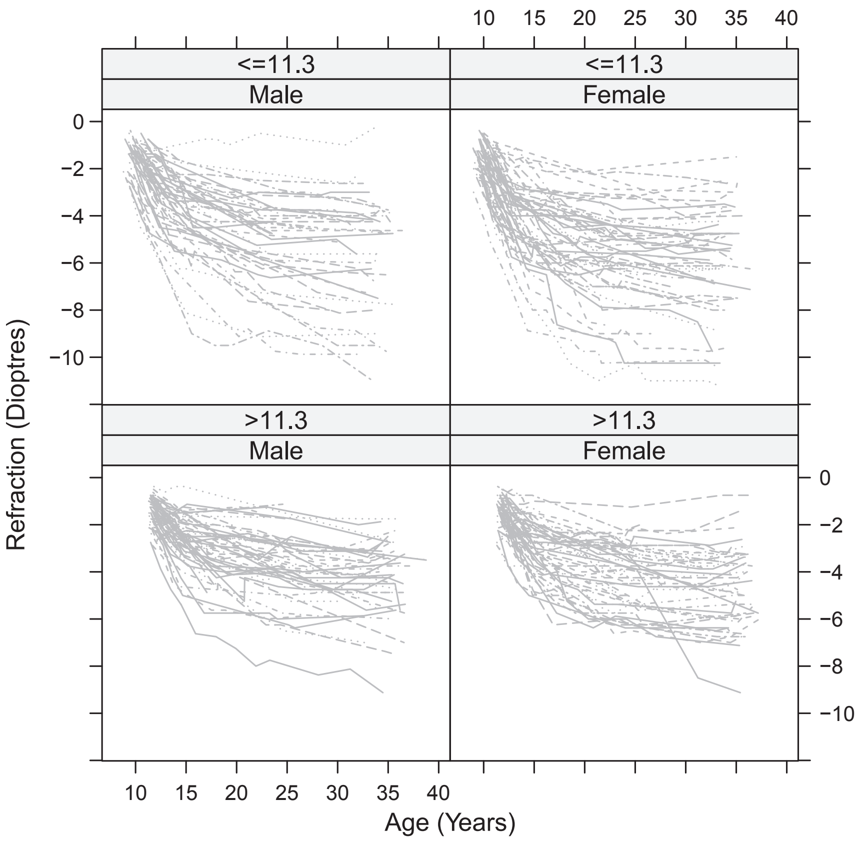

Fig. 1. Individual progression curves of spherical equivalent (refraction in dioptres) of the right eye. Refraction values comprise all the measurements obtained during the follow-up separately for both sexes according to median age (11.3 years.) at Baseline.

Table 1. Percentage distribution of changes in spherical equivalent (SE) between different ages.

	Follow-up point with age ranges		
Follow-up points	3→4	3→5	4→5
Age range (y)	12–16→20–24	12–16→25–39	20–24→25–39
N	169	181	147
Change of SE (D)			
+1.50 to +2.00	0.0	0.0	0.6
+1.00 to +1.49	0.0	0.0	0.0
+0.50 to +0.99	0.6	1.2	3.4
+0.49 to −0.49	11.4	3.9	51.2
−0.50 to −0.99	14.9	9.9	27.3
−1.00 to −1.49	18.5	17.7	12.3
−1.50 to −1.99	17.3	16.6	3.5
−2.00 to −2.49	16.8	15.5	1.4
−2.50 to −2.99	8.4	14.9	0.0
−3.00 to −3.49	5.4	3.3	0.0
−3.50 to −3.99	1.8	6.7	0.0
−4.00 to −4.49	3.6	3.9	0.0
−4.50 to −4.99	0.6	2.2	0.0
−5.00 to −5.49	0.0	0.6	0.0
−5.50 to −5.99	0.6	0.6	0.7
−6.00 to −6.49	0.6	1.7	0.0
−6.50 to −6.99	0.0	0.6	0.0
Mean change of SE (D) ± SD	−1.68 ± 1.14	−2.12 ± 1.30	−0.45 ± 0.71
Mean change of SE/y (D) ± SD	−0.19 ± 0.13	−0.12 ± 0.08	−0.05 ± 0.09
Mean age change (y)	9.03	17.28	8.25

SE = spherical equivalent, SD = standard deviation, y = year.

differences in Reading, Outdoor or TV time or reading distance at Baseline. The effect of parents' myopia on the different progression of myopia between the sexes was almost significant from Baseline to Follow-up 1 ($p = 0.051$, sex * parents' myopia interaction term in repeated-measures ANOVA model), but not thereafter.

Parents' myopia and myopic progression

The age of commencing to the study (onset of myopia) was not associated with having parental myopia (mean age 10.75 years) or not having parental myopia (mean age 11.06 years) ($p = 0.063$, independent-samples *t*-test). There was also no statistical difference in SE at beginning of the study in this respect ($p = 0.373$). Figure 2 shows the myopic progression in these two different hereditary groups, one or both parents myopic and no myopic parents. The difference between the groups in the means of refraction gradually increased. Myopic progression was faster between the Baseline and first follow-up among those whose parents were myopic ($p = 0.022$, repeated-measures ANOVA with repeated contrasts). The difference in the last adulthood SE between the parental myopia groups was also significant ($p = 0.016$, independent-samples *t*-test).

Bifocal treatment, accommodation stimulus and reading distance

At the end of the 3-year treatment, myopic progression was not slowed down by using bifocals or by Reading without spectacles (Pärssinen et al. 1989). Thereafter, the children received ordinary fully corrected spectacles with a recommendation of continuous use. Myopic progression up to Follow-up 5 was −3.67 D ± 1.64 in the continuous-use group, −3.67 D ± 1.97 in the distant-use group and −3.76 D ± 1.85 in the bifocal group, with no significant differences between the groups ($p = 0.944$). There were also no significant differences in myopic progression between the treatment groups when males and females were analysed separately. Thus, in the analyses of this study, the treatment groups are not taken into account.

When the average reading distance calculated from four measurements at childhood and SE at the end of the

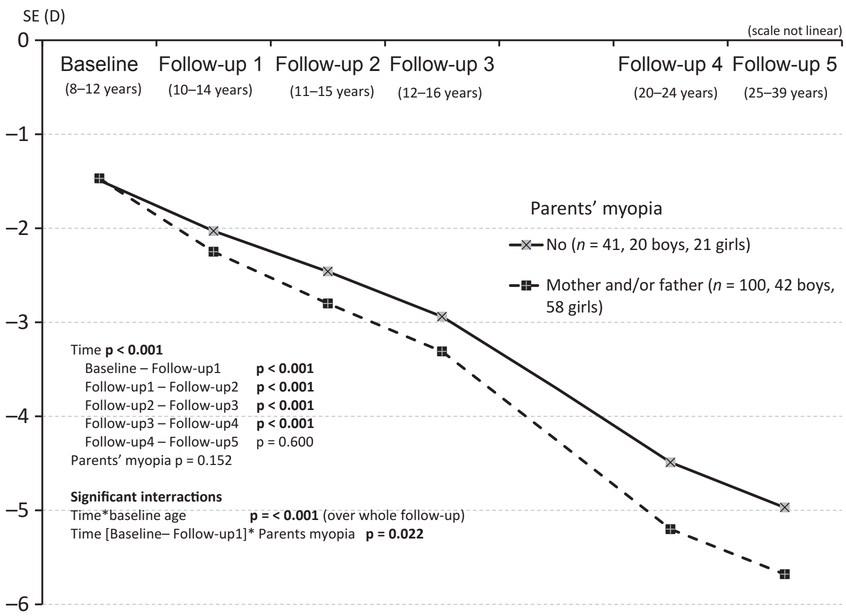

Fig. 2. Spherical equivalent (SE) in dioptres (D) with regard to parents' myopia during the follow-up. Statistical tests are based on repeated-measures ANOVA with repeated contrasts.

3-year follow-up and at the two adult ages was compared, significant correlations were observed among females, and when both sexes were combined (Table 2), the shorter the reading distance in childhood, the greater the myopia in adulthood. However, the correlation did not hold among males. Among females, the correlations between childhood reading distances and SE at different ages remained significant, also after controlling for the age of myopia onset and body height at the respective ages. However, the less the childhood accommodation stimulus, the greater the myopia in childhood, but accommodation stimulus in childhood did not correlate with SE in adulthood.

Time spent on reading and close work (Reading) and academic attainment and myopic progression

The more the daily Reading time, the greater the rate of myopic progression during the first 3-year clinical follow-up in childhood ($r = 0.253$, $p = 0.001$, Pearson product moment correlation). When studying the connection between myopic progression during the whole follow-up and Reading (as well as Outdoor and TV), the best differentiation was seen with the cut-off time of 3 hr. Although there was a trend for greater myopic progression during the whole follow-up among those Reading more (>3 hr versus ≤3 hr), the difference in myopic progression between these groups was not statistically significant ($p = 0.756$, repeated-measures ANOVA with repeated contrasts) (Fig. 3). The difference in the change in SE between the Reading groups was not statistically significant ($p = 0.497$, Time * Reading group interaction term). However, 6.9% and 5.4% of myopic progression during the first follow-up year after myopia onset was explained by Reading ($r = 0.260$ and 0.230 among boys and girls, respectively, Pearson product moment correlations). There were no significant correlations between the last SE at the 35-year clinical follow-up and either the last GPA at school ($r = -0.019$, $p = 0.844$) or years of education ($r = -0.065$, $p = 0.471$).

Time spent on sports and outdoor activities (Outdoor) during school age and myopic progression

Figure 4 shows the change in myopia among those who spent 0.5–3 hr on Outdoor activities during school age compared with those whose Outdoor time was >3 hr. The difference between these groups gradually increased and was significant ($p = 0.041$, repeated-measures ANOVA with repeated contrasts) throughout the follow-up, that is, myopia increased faster among those who reported less Outdoor time ($p = 0.012$, Time * Outdoor activity group interraction in repeated-measures ANOVA model).

Time spent watching television (TV) and myopic progression

Figure 5 shows the connection between the time spent on TV and myopic progression. Myopia was greater among those whose daily TV-watching time was 0.5–3 hr. The difference remained quite similar and was almost significant from the beginning throughout the follow-up ($p = 0.065$, repeated-measures ANOVA with repeated contrasts).

Correlations between final SE and different time-spending patterns

We further analysed the correlations between the SE at Follow-up 5 and

Table 2. Correlations of spherical equivalents with childhood reading distance and accommodation stimulus at different ages. The correlations are shown separately for males and females and for both sexes together.

	Childhood reading distance			Childhood accommodation stimulus		
Age years	*n*	*r*	p	*n*	*r*	p
Males						
12–16	118	0.044	0.635	115	0.243	**0.009**
20–24	77	0.139	0.229	74	0.059	0.616
25–39	85	0.038	0.728	83	0.221	0.055
Females						
12–16	116	0.243	**0.009**	113	0.168	0.076
20–24	93	0.285	**0.006**	90	0.086	0.421
25–39	93	0.260	**0.010**	95	0.059	0.570
Total						
12–16	234	0.151	**0.017**	228	0.201	**0.002**
20–24	170	0.223	**0.003**	164	0.081	0.302
25–39	183	0.169	**0.022**	178	0.126	0.096

r = Pearson product moment correlation coefficient. Statistically significant correlations are in bold.

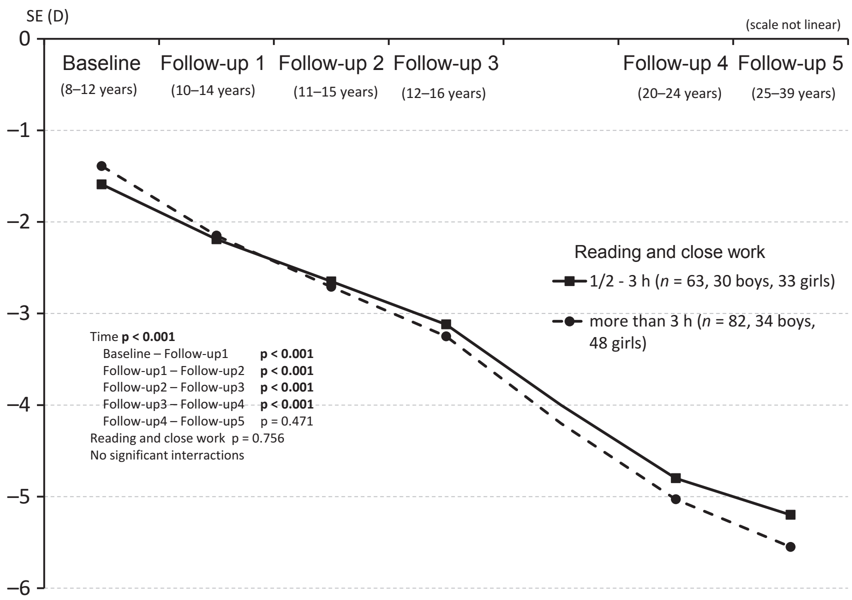

Fig. 3. Spherical equivalent (SE) in dioptres (D) with regard to childhood time spent on Reading and close work during the follow-up. Statistical tests are based on repeated-measures anova with repeated contrasts.

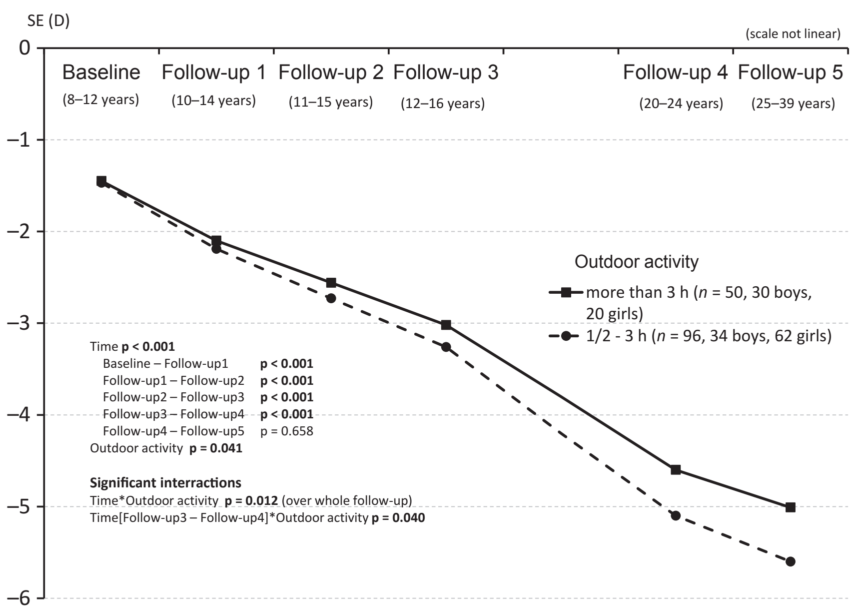

Fig. 4. Spherical equivalent (SE) in dioptres (D) with regard to childhood time spent on sports and Outdoor activities. Statistical tests are based on repeated-measures anova with repeated contrasts.

different combinations of amounts of time spent on different activities in childhood. The correlation between Reading and final SE was not significant ($r = -0.119$, p = 0.092, Pearson product moment correlation), neither the combined time TV and Reading showed no correlation with final SE ($r = -0.040$, p = 0.574). On the other hand, when TV and Outdoor time was combined, the correlation with SE was slightly higher ($r = 0.144$, p = 0.040) than that found between Outdoor time and SE ($r = 0.135$, p = 0.054), that is, the greater the TV and Outdoor time together at childhood, the less the last SE.

Stability of time-spending patterns and their interrelationships

The amount of Reading, Outdoor and TV time was elicited twice during childhood, and the means of these values were used in the further analyses. The same questions were answered at the two adult clinical follow-up visits. Table 3 shows the correlations between these variables at different ages. The correlations between the same activities at different ages were all positive. Only the correlation between Reading at childhood and at 35-year follow-up (including computer work) did not reach level of significance ($r = 0.166$, p = 0.061). Thus, the predisposition to these activities seems to continue from childhood to adulthood.

There were negative correlations between Reading and Outdoor times at all three observation point, but the correlation was non- significant at childhood. The correlations between TV and Outdoor times were positive at all three observation points but did not reached the level of significance at 35-year follow-up. Thus, it seems that those who read more spend less time at Outdoors and those who spend more time Outdoors spend also more time at watching TV.

Discussion

As far as we know, our study is the longest clinical follow-up study of the progression of myopia from its onset at school. One challenge in such a lengthy follow-up study is the possible confounding effect of dropout. It might be suggested that those whose myopia had progressed would be more likely to participate in the clinical follow-up examinations. In this study, the 3-year follow-up was implemented for almost all participants (238/240). Percentage participation at the two subsequent clinical examinations was 74.6% and 55.3%. However, the main reasons for non-participation in the last clinical examination were living abroad or no address available, or living far from the examination centre or busy work schedules. Only 16 (6.6%) of the study subjects who did not participate lived less than about 100 km from the study centre. Thus, it can be suggested that more stable myopia was not particularly strong reason for non-participation in the study.

Several cross-sectional studies have shown higher myopia prevalence in the younger generations than among older age groups (Aine 1984; Pärssinen 1987). There have been also suggestions that myopic refraction at a young

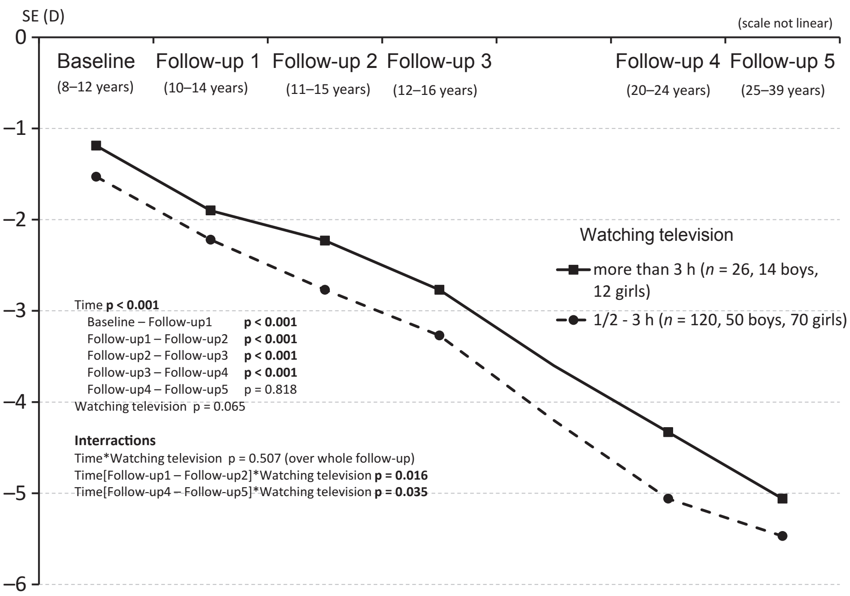

Fig. 5. Spherical equivalent (SE) in dioptres (D) with regard to childhood time spent watching television. Statistical tests are based on repeated-measures anova with repeated contrasts.

age could change to emmetropia or hyperopia at later ages (Fledelius 1983). In the present material, about half of the cases were stable (within range ±0.5 D) in adulthood after age 20–24, but in 45% of the cases, myopic progression continued. In a few cases only, some decrease in myopia occurred, but after excluding three pathological cases, there were no instances of myopia changing to hyperopic refraction. Thus, it can be assumed that no significant trend towards hyperopia exists among myopics, at least before presbyopic age.

The mean annual increase in myopia after age 25 in this study was −0.05 D ± 0.09, which is not far from the −0.07 D ± 0.09 and 0.03 D ± 0.09 for males and females between the ages of about 20 to 25 found by Goss et al. in optometry practices (Goss et al. 1985).

Gender

In this study, myopia progression was faster among girls than boys up to adulthood. Many studies have shown higher myopia prevalence among females in different age cohorts (Midelfart et al. 2002; Pärssinen 1987; Shih et al. 2010, Sun et al. 2012). However, more myopia has also been reported among males (Shrestha et al. 2010), and some studies have observed no gender differences (Rezvan et al. 2012). The variables used in this study did not explain the gender differences in myopic progression.

Heredity

Family history of myopia has been a significant factor associated with myopia in different age cohorts (Mutti et al. 2002; Jones et al. 2007; Low et al. 2010). In the study by Low et al. (2010), a family history of myopia was the strongest factor associated with preschool myopia. Conversely, in their study of military conscripts, Saw et al. (2001) initially found a positive association between parental myopia and myopia ($p < 0.001$); however, this relation disappeared when adjusted for environmental factors. In contrast, in the present study, neither near-work nor outdoor activity was found to be associated with early myopia. These data suggest that genetic factors may play a more substantial role in the development of early-onset myopia than key environmental factors. Genomewide meta-analyses have identified multiple susceptibility loci for refractive error and myopia (Verhoeven et al. 2013). The results of a recent genomewide association study on age of onset of myopia suggest that the genetic predis-

Table 3. Correlations between time-spending patterns during childhood and at ages 24 and 35.

Activities at different ages		Reading, childhood	Outdoor, childhood	TV, childhood	Reading, 24 years	Outdoor, 24 years	TV, 24 years	Reading, 35 years	Outdoor, 35 years
Outdoor, childhood	*r*	−0.095							
	p	0.148							
Television, childhood	*r*	0.155	0.150						
	p	**0.018**	**0.022**						
Reading, 24 years	*r*	0.196	−0.100	−0.079					
	p	**0.009**	0.187	0.299					
Outdoor, 24 years	*r*	−0.102	0.278	0.034	−0.222				
	p	0.179	**0.000**	0.656	**0.003**				
Television, 24 years	*r*	−0.101	0.208	0.325	−0.175	0.234			
	p	0.183	0.006	**0.000**	**0.020**	**0.002**			
Reading*, 35 years	*r*	0.166	−0.199	−0.029	0.492	−0.142	−0.178		
	p	0.061	**0.024**	0.747	**0.000**	0.129	0.056		
Outdoor, 35 years	*r*	0.058	0.218	0.081	−0.040	0.263	0.261	−0.300	
	p	0.515	**0.014**	0.366	0.669	**0.005**	**0.005**	**0.001**	
Television, 35 years	*r*	−0.031	0.106	0.175	−0.161	0.207	0.374	−0.090	0.112
	p	0.732	0.232	**0.047**	0.084	**0.027**	**0.000**	0.310	0.209

r = Pearson product moment correlation coefficient, TV = time used for watching television.
Statistically significant correlations are in bold.
* includes computer work.

position to age of onset of myopia is regulated by the same genes as the degree of refractive error (Kiefer et al. 2013). The Baseline refraction values of the subjects in this study were rather homogenous due to the study design, which also explains why the SE of those with or without myopic parents did not significantly differ from each other at study outset. The subsequent higher progression of myopia among those with myopic parents indicates that some genetic factor causes myopic progression to increase also in adulthood.

Reading distance and accommodation stimulus

The main reason for this study was at the beginning to examine whether myopic progression could be slowed down by reducing accommodation with bifocals or by reading without glasses. During the 3-year follow-up, the rate of myopic progression was actually slightly lower among participants using spectacles continuously (Pärssinen et al. 1989). Although in some studies, bifocals have been beneficial, especially in esophoric children with a large lag in accommodation, and most studies have yielded results similar to those presented here (Walline et al. 2011; Cooper et al. 2012). The calculated accommodation stimulus during childhood in this study was contrary to expectations less among those whose myopic progression was faster (Pärssinen et al. 1989). However, no correlation was found between childhood accommodation stimulus and amount of myopia in adulthood. Interestingly, short reading distance in childhood predicted higher myopia in adulthood among females, but not among males. An association between short reading distance and myopia has also been shown in other studies (Rah et al. 2002; Lee et al. 2013). Ip et al. (2008) found that near work such as close reading distance (<30 cm) and continuous reading (>30 min) independently increased the odds for myopia in a sample of children. They suggested that the intensity of reading rather than the total duration of near work is an important factor in the progression of myopia. The present author (OP) has previously hypothesized that the fast saccadic eye movements produced during reading could be one link with short reading distance and the development of myopia (Pärssinen 1990, 2012). Skilled readers move their eyes, on average, every quarter of a second when reading (Rayner 1985). This means up to 14 400 saccades per hour. Every eye movement causes a stretching effect around the muscle insertions and an indentation pulse on the scleral tissue. The closer and more intense reading is, the higher these mechanical stretch strain pulses are on the scleral tissue. One might reasonably assume that children, in particular, whose eyes still are growing, would be more vulnerable to such an effect. However, without well-planned prospective studies, it is difficult to prove whether there are causal relationships between these factors or whether short reading distance is a consequence of myopia.

Reading and close work, outdoor activities, watching TV and academic performance

The times used to different activities can vary at different ages and different life situations. However, the answers to the same questions about daily activities received at adulthood control visits correlated quite well with the same questions at childhood. It is difficult to say whether childhood activities influence on myopic progression up to adulthood or was the connection between these factors depending on the fact that the propensity to different activities seems to continue to adulthood.

Previous studies have shown that myopic progression is connected with academic achievements and more reading also at adulthood (Kinge et al. 2000; Jacobsen et al. 2008). In a 3-year longitudinal study of Kinge et al. (2000), myopic change among students was significantly related with reading and near-work time, but not with time spent at working with video display terminals. All the subjects of this follow-up study were myopic children without previous spectacles. In this respect, the participants were homogenous. They were also homogenous in length of education (≥12 years in 93% of cases). The fact that there were no emmetropes or hyperopes among them may weaken the possible causal effects on myopia of external factors. The main connection between external factors and myopic progression was the slower rate of myopic progression among those who spent more, compared with those who spent less, than 3 hr daily on outdoor activities in childhood. Significant correlations were observed between the amounts of outdoor, reading and TV time in childhood and adulthood. It is therefore hard to say whether the associations derive from childhood or from continuing differences in these habits. The correlations between myopic progression and reading and outdoor time found in this study were rather weak. Jones-Jordan et al. (2012), who followed-up already myopic children for 1 year, found, at an *a priori* level of $p \leq 0.01$, no significant associations between annual myopic progression and either the number of hours of reading for pleasure per week, other activities requiring near sight, the near-work composite variable dioptre-hours or outdoor/sports activity. While it may be suggested that reading is connected with the incidence of myopia, the differences in reading among the already myopic individuals in this study showed little influence on the rate of myopic progression.

Several studies have suggested that less time spent on sports and outdoor activities has a stronger association with myopia than more time spent on reading and close work (Jones-Jordan et al. 2011; Yi & Li 2011; Sherwin et al. 2012). In this study, TV time differentiated the study subjects from the outset: the more TV time, the less myopia. The ‘myopia protective correlation’ of outdoor activities slightly increased when outdoor and TV times were combined, whereas when reading and TV were combined, the correlation with myopic progression decreased. Thus, for preventing myopic progression, it might be more beneficial to spend more time away from reading, whether it is watching TV or just being outdoors.

Higher academic performance has also been associated with myopia (Goldschmidt 1968). In this study, no such connections were found. This, too, could be due to the considerable homogeneity of the study subjects in terms of education. In Finland, compulsory education begins at the age of seven. In many South and East Asian countries, children begin school much earlier and, at least partly due to educational competition, spend much more time in reading and close work than being outdoors. Baldev et al.

(1990) studied the prevalence of myopia among 10- to 12-year-old schoolchildren from different schools in India. The prevalence of myopia was 60%, 41.9% and 18.4% among those beginning school at ages 3–4, 4–5 and >5 years, respectively. Although myopia has increased worldwide during the recent decades, the increase has been much greater in the South and East Asian countries. While this might have a hereditary component related to race, at least part of the difference could be connected to differences in the age of starting school. In addition, could different writing systems affect refraction? One could speculate that alphabetic orthographies (e.g. English) are easier to learn and read than, for example, logographic orthographies (e.g. Chinese). We would argue that the mechanical effects of the reading process, especially the continuous and repeated stress strain pulses on scleral tissue, and their effects on the still-growing eyeball of young children merit more detailed study.

Conclusion

In our long-term follow-up of myopic children, in nearly half of the cases, myopic progression starting at a young school age continued in adulthood. Higher adulthood myopia was mainly associated with female sex, parental myopia and less time spent on sports and outdoor activities in childhood. Reading without glasses or use of bifocals to reduce accommodation stimulus during childhood did not correlate with adulthood refraction. Short reading distance in childhood predicted higher adulthood myopia among females but not males. Time spent on reading and close work in childhood was associated with myopic progression during the first 3 years but did not predict myopia in adulthood.

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Correspondence:
Olavi Pärssinen
Koulukatu16 A 13
33200 Tampere
Finland
Tel: +358405876304
Fax: +358142601021
Email: olavi.parssinen@top.fimnet.fi